smiths

DARPA Bidder's Conference SN02-23

Prognostics and Health Management at Smiths Aerospace - Electronic Systems

Mr. Tom Conquest

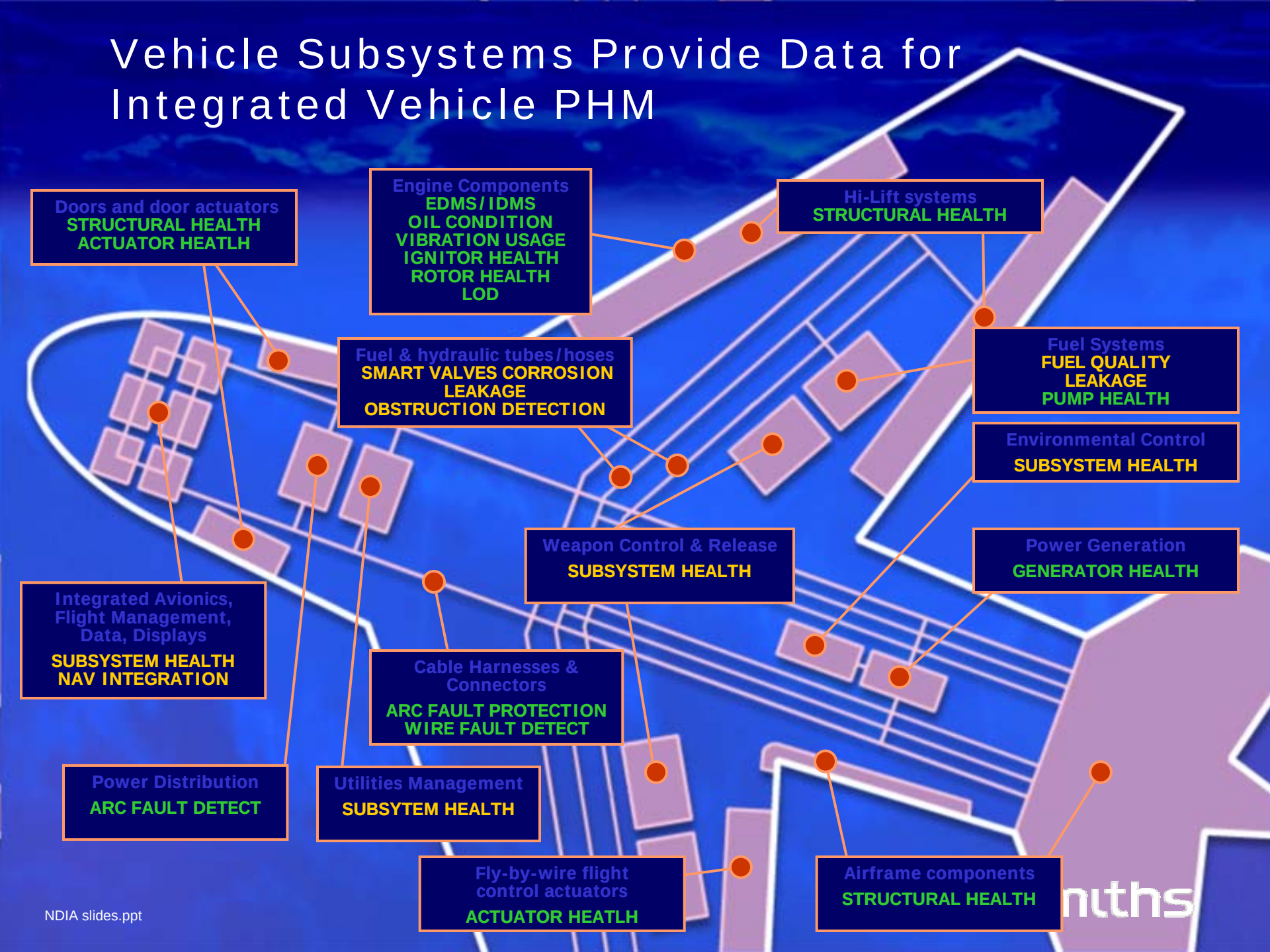
September 26, 2002

engineering value in aerospace

Recognized Need for Military PHM

- JSF
  - Requirement for 98% automated detection of all functional failures
- UAV
  - Autonomous, real-time availability of health status
- FCS
  - BIA calls for Logistics Decision Support, UAVs, Health Monitoring

Vehicle Subsystems Provide Data for Integrated Vehicle PHM



Electrostatic Sensors

EDMS Sensors

Wear-site sensor (WSS)

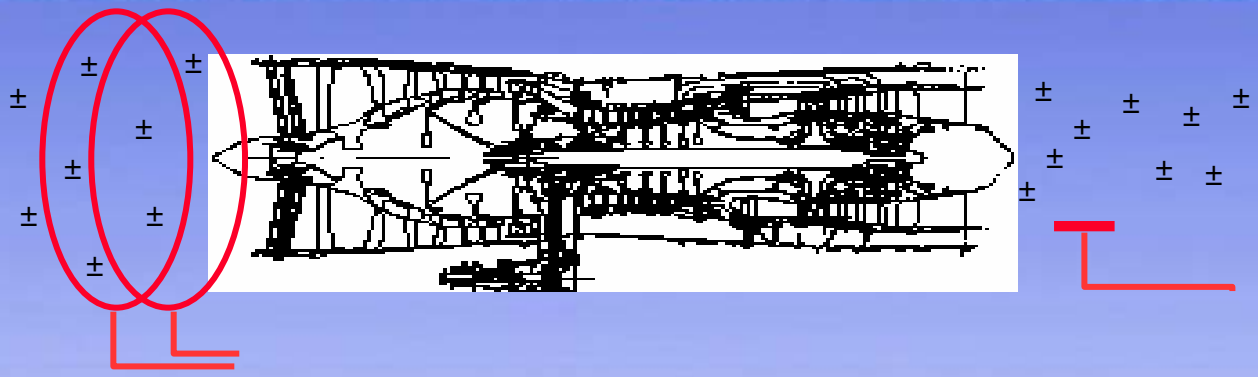
- specific component
- onset of wear

Oil-line sensor (OLS)

- wear debris
- oil degradation / contamination

smiths

Gas Path Debris Turbine Engine Monitoring



Ingested Debris Monitoring System (IDMS)

Engine Distress Monitoring System (EDMS)

IDMS: 2 ring sensors installed in/on the intake

Signal conditioning

EDMS: Button sensor installed in exhaust duct

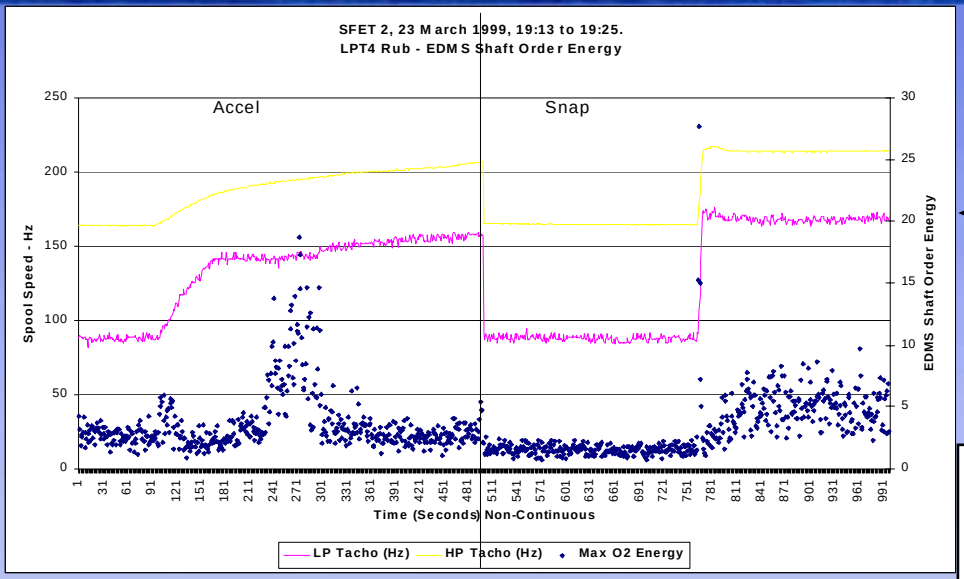
Signal conditioning (integrated)

Data acquisition and processing - include in engine PHM Unit

Correlation EDMS, IDMS, engine parameters, flight information etc

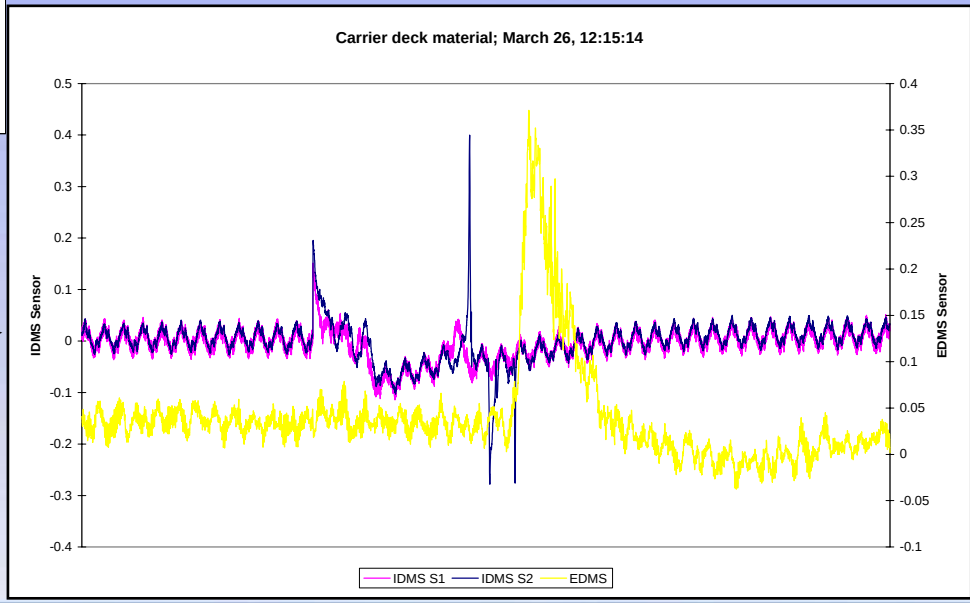
smiths

EDMS/IDMS Results



← SFET - LPT4 Rub

Ingestion Tests
Carrier Deck Material →



smiths

Potential Benefits of Technology

Inlet

- Detection and discrimination
  - Damaging/ non-damaging/ particulate FOD
  - 'Fluids', e.g. salt water
- Identify operating situations where FOD occurs
- Identify:
  - that damaging object has been ingested
  - whether object has caused immediate damage to the engine
- Correlation with EDMS

Exhaust

- Direct indication of fault
- Early detection prognostic/prediction
- Operational benefits
  - Reduce consequential damage
  - Reduce maintenance costs & time, Improve maintenance scheduling
  - Increase availability, repair when necessary
- Detection of 'difficult to monitor' faults
  - Combustor related faults
- Dual functionality
  - LOD + EDMS

Oil

- **Wear-site precursor detection**
  - Wear site sensor (WSS)
  - Early warning of component degradation
    - essential when time to failure is short and will result in significant secondary damage
  - Pre-maintenance operational guidance
    - safe return to base for repair / maintenance
- **Oil-line monitoring**
  - Oil Line Sensor (OLS)
  - Non-metallic, metallic and ferrous debris
  - Sensitivity to smaller (~20μm) debris
  - Oil degradation / contamination

FUMS™, A Flight Usage Management System

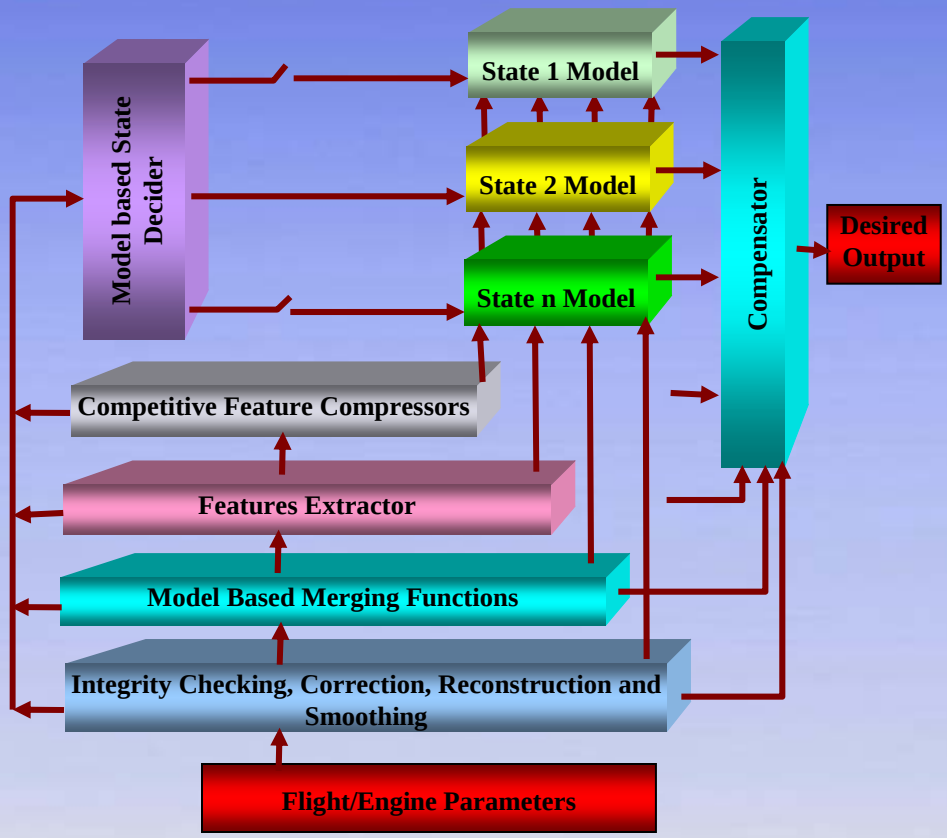
- **FUMS™ provides:**
  - **Flight data display, analysis and prognostics to optimize aircraft Management, Affordability, Availability, Airworthiness and Performance (MAAAP)**
  - **Component-level usage, life and condition management**
  - **Virtual sensors via model-based data synthesis**
  - **User friendly fusion, mining, trending and intelligent force management**
  - **User friendly interfaces with logistics/maintenance databases (for example, MOD HUMS and Oil Wear Debris databases)**

FUMS™ is a single software framework currently operating on real data downloaded from various aircraft data collection systems on Eurofighter, F16, Tornado, Harrier, Chinook, Lynx, Apache, RB199 & Pegasus.

smiths

FUMS™, A Flight Usage Management System

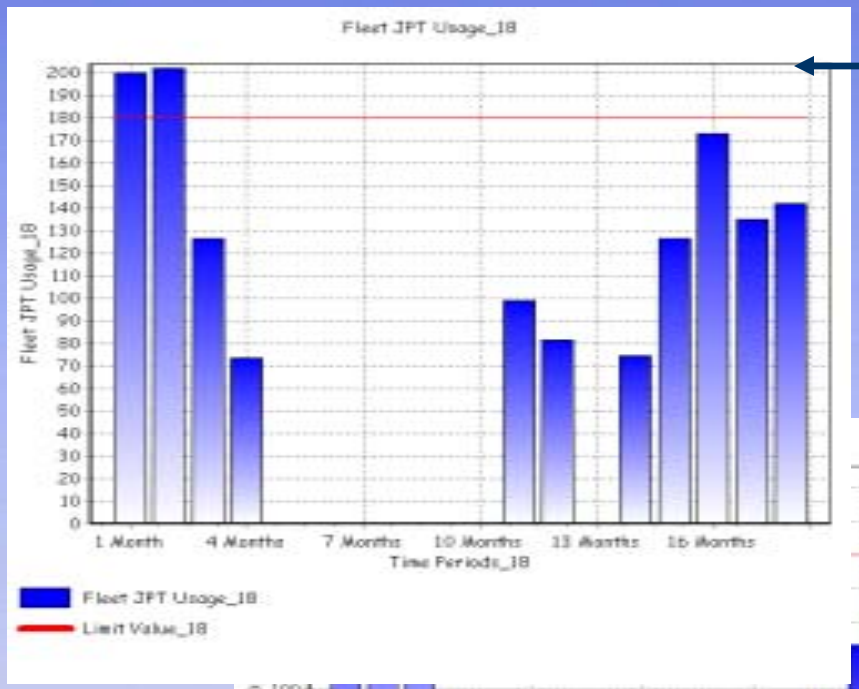
- Real-time structural integrity status and individual aircraft tracking
- Model-based usage indices to summarise flight data and at the same time indicate the life and condition of aircraft/engine components.
- Synthesis of strains from flight data via mathematical networks and, hence, elimination of the high operational costs required for maintaining a large number of strain gauges on each individual aircraft
- Synthesis of operational parameters (e.g. AUM, CG)
- Synthesis of damage/fatigue from flight data (model-based damage models)
- Conventional damage/fatigue models



Mathematical Network

smiths

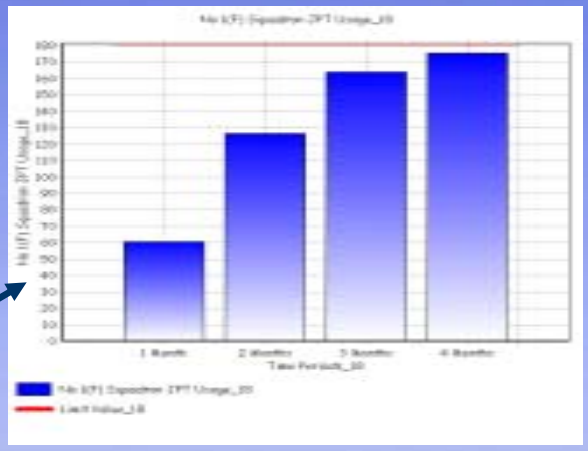
FUMS™ : Force Management

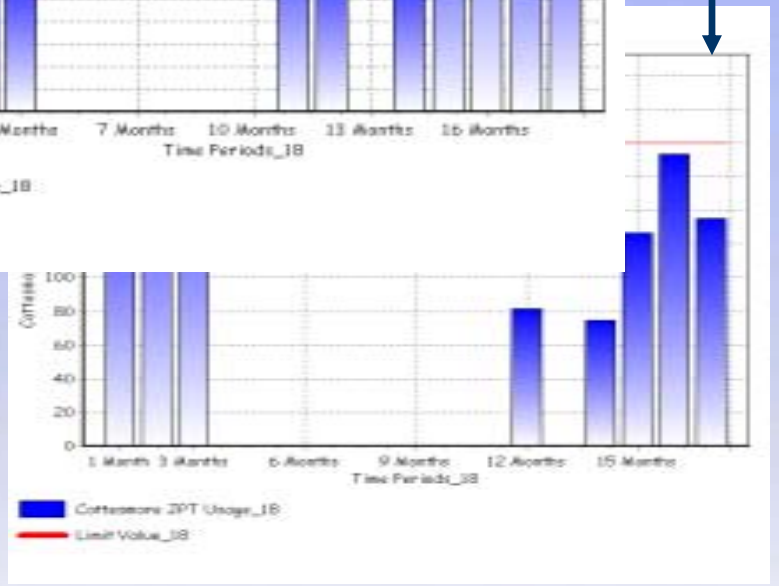


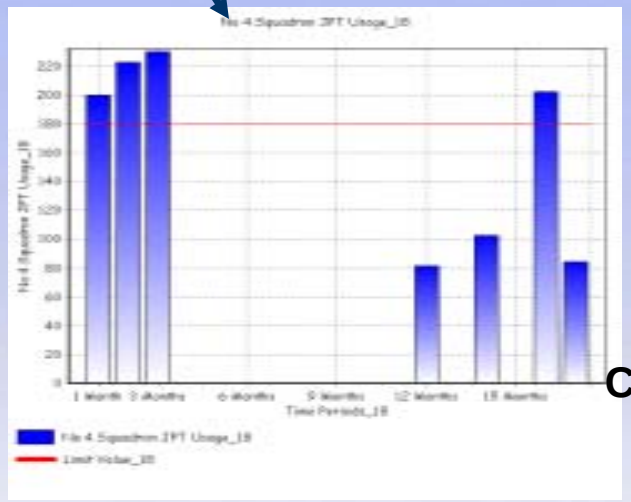
Fleet usage status

Station usage

Squadron Usage





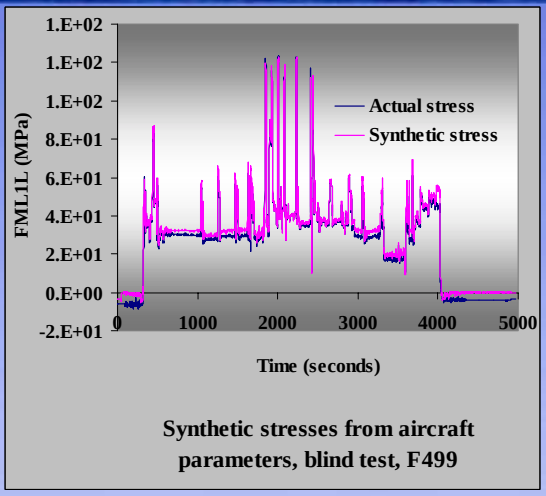


Aircraft /engine usage

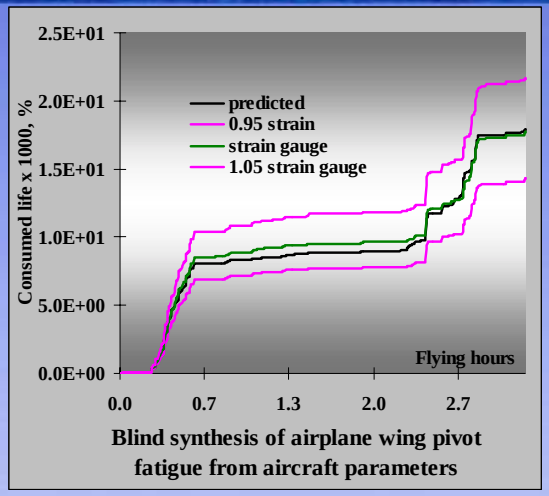
Component usage

smiths

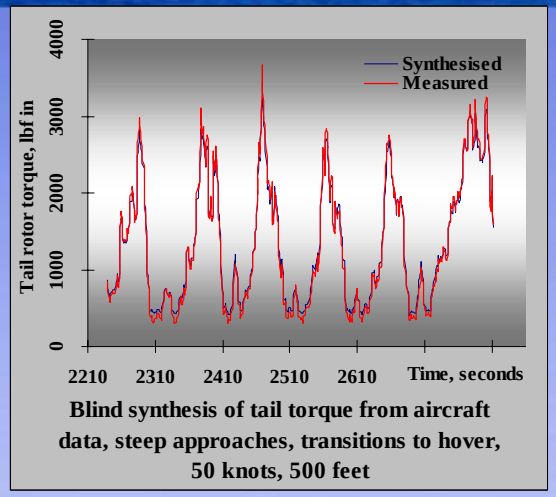
FUMS™ : Some of the PHM Models/Information



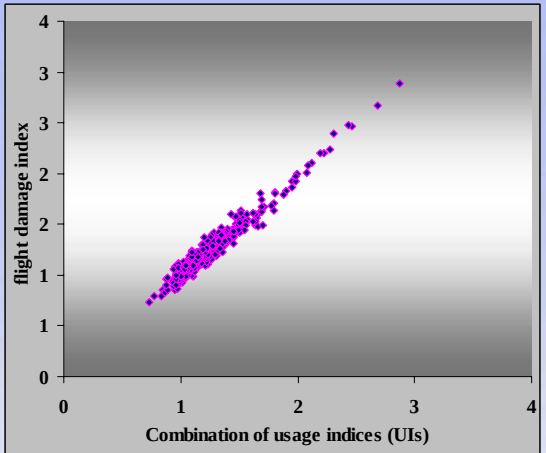
Synthetic stresses from aircraft parameters, blind test, F499



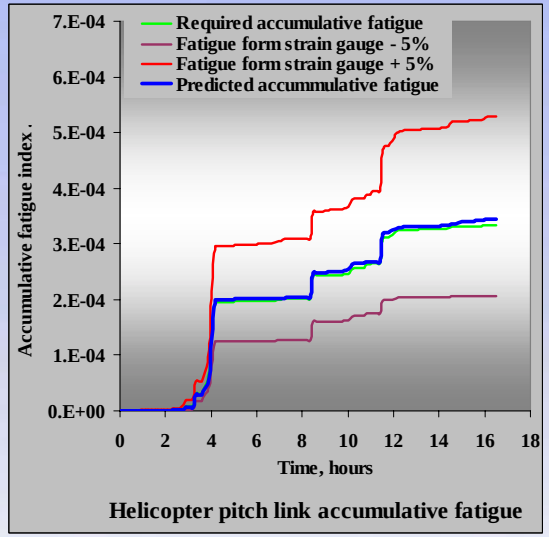
Blind synthesis of airplane wing pivot fatigue from aircraft parameters



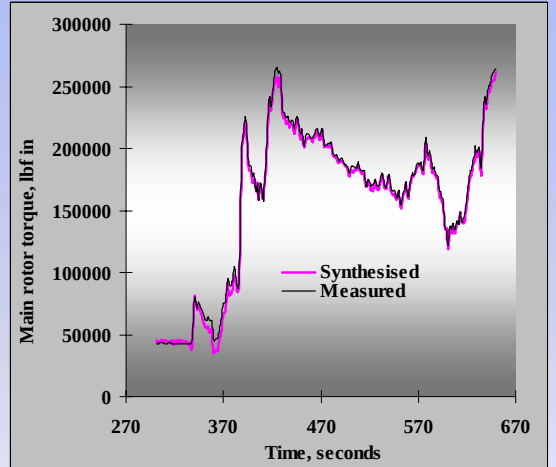
Blind synthesis of tail torque from aircraft data, steep approaches, transitions to hover, 50 knots, 500 feet



High Pressure Turbine (HPT) cover-plate damage trend with UIs



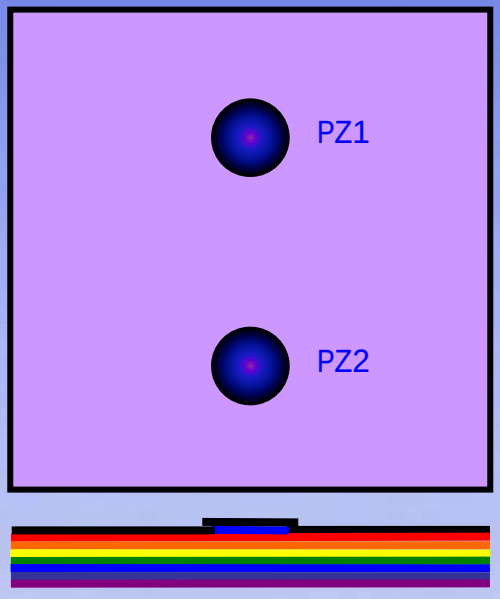
Helicopter pitch link accumulative fatigue



Blind synthesis of main rotor torque from aircraft data

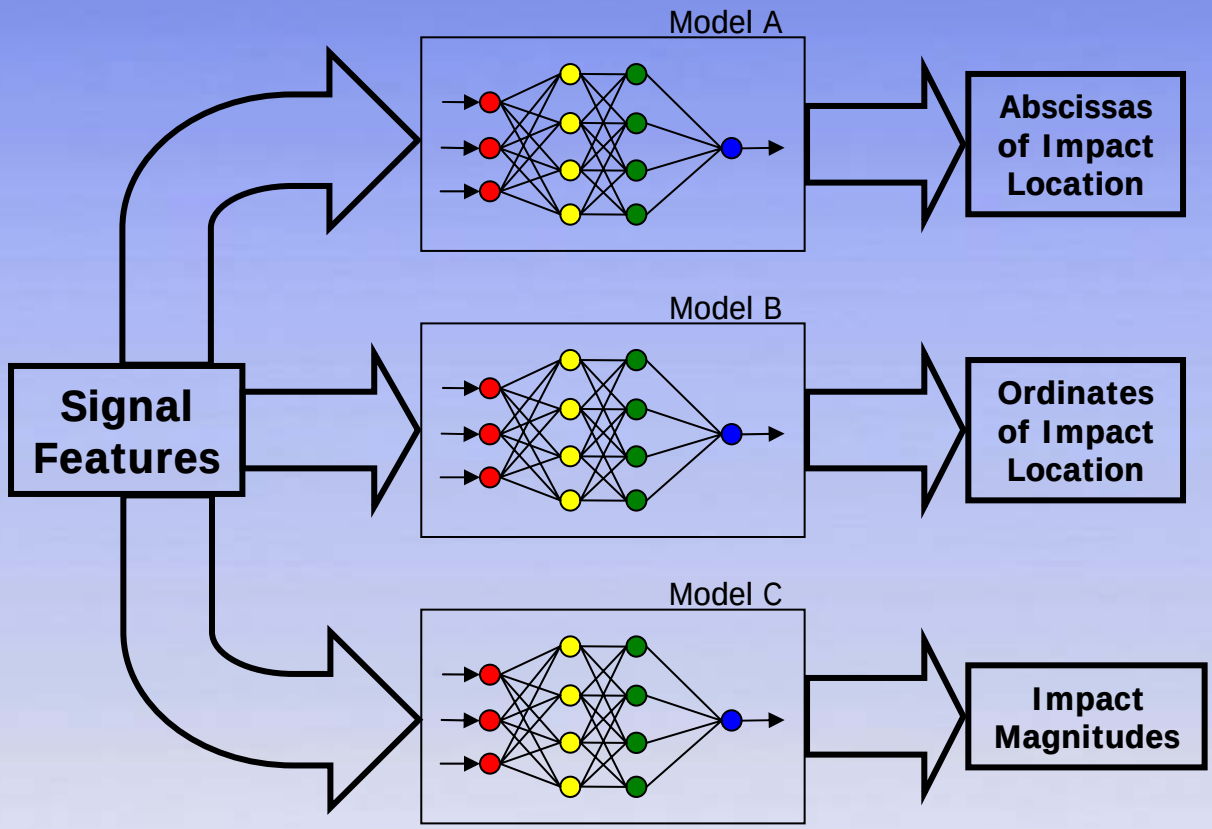
smiths

Active Matrix Composites



Piezo Embedded 8 layer Composite

ANFIS - Adaptive Neuro-Fuzzy Inference System



smiths

ProDAPS

- **Uses advanced AI tools to provide a probabilistic, knowledge rich, framework to do the following:**
  - Integrate all available types of engine monitoring data
  - Provide advanced data analysis capabilities to maximize the available information
  - Fuse data from all sources to provide more accurate diagnostics and prognostics
  - Support the user in optimum decision making
  - Improve its performance through the mining of historical data to discover new knowledge
- **Provides a flexible, component based, architecture where components can be configured for specific applications**

Key Features of ProDAPS

Sensors

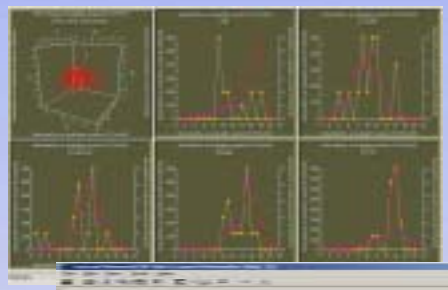
Knowledge

Situation Awareness
Diagnostics & Prognostics
Anomaly Detection

Decision Networks

Decision Support

Comprehensive Data Analysis

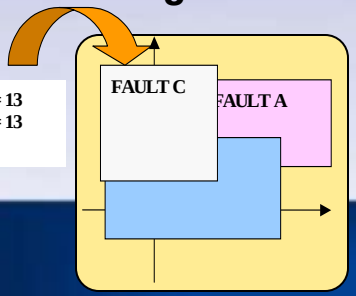


Data Feature and Decision-level Fusion

Causal Networks

Data Mining and Knowledge Discovery

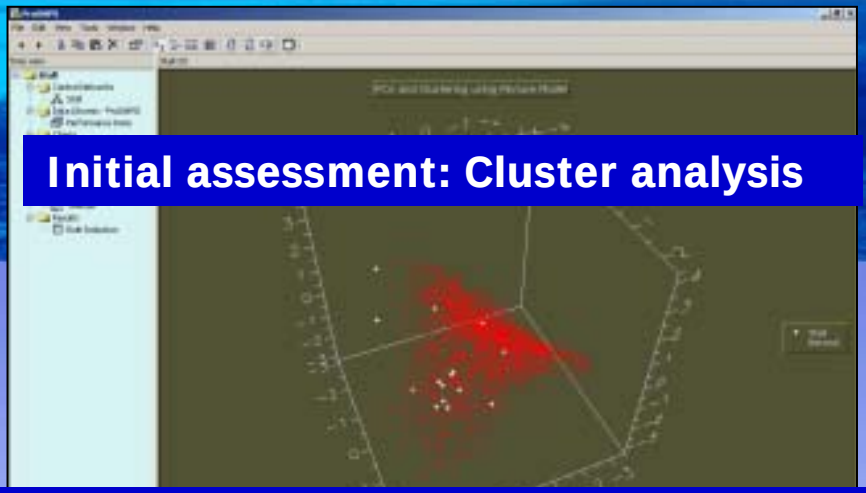
IF THMCLR = 7 AND N2 = 13
IF THMCLR = 9 AND N2 = 13
IF TT2 = 12 AND N2 = 15



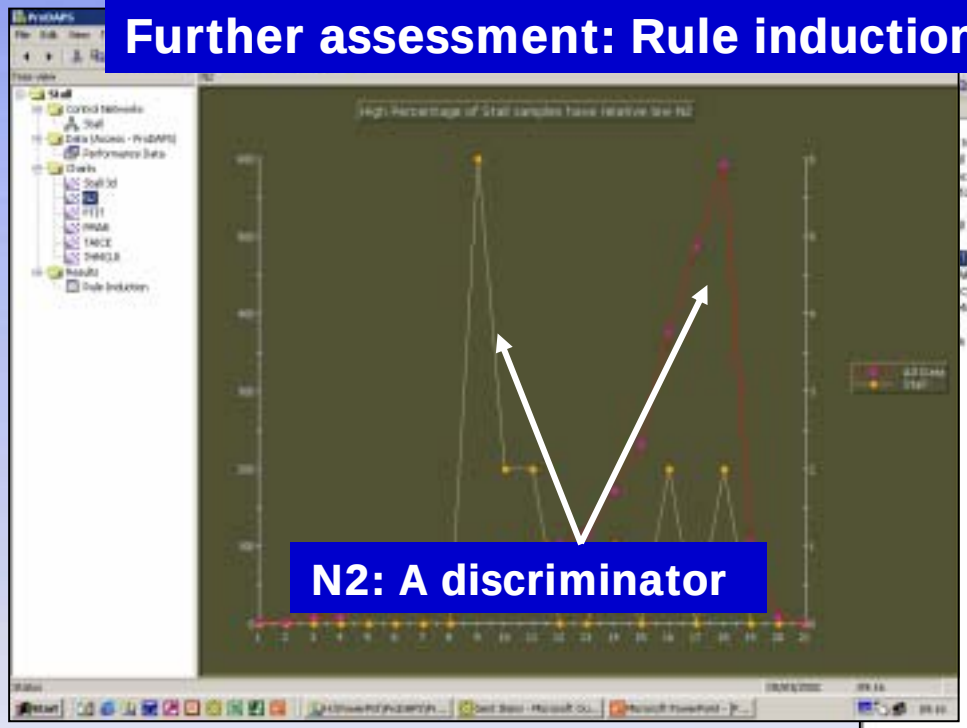
- **Benefits**
  - On-Condition Maintenance - or -
  - Reliability Centered Maintenance
  - Reduced costs of ownership
  - Better maintenance planning
  - Improved diagnostic accuracy
  - Failure prediction from intelligent reasoners
  - Probabilistic prognostics predicts future health based on current health and condition and future usage profiles

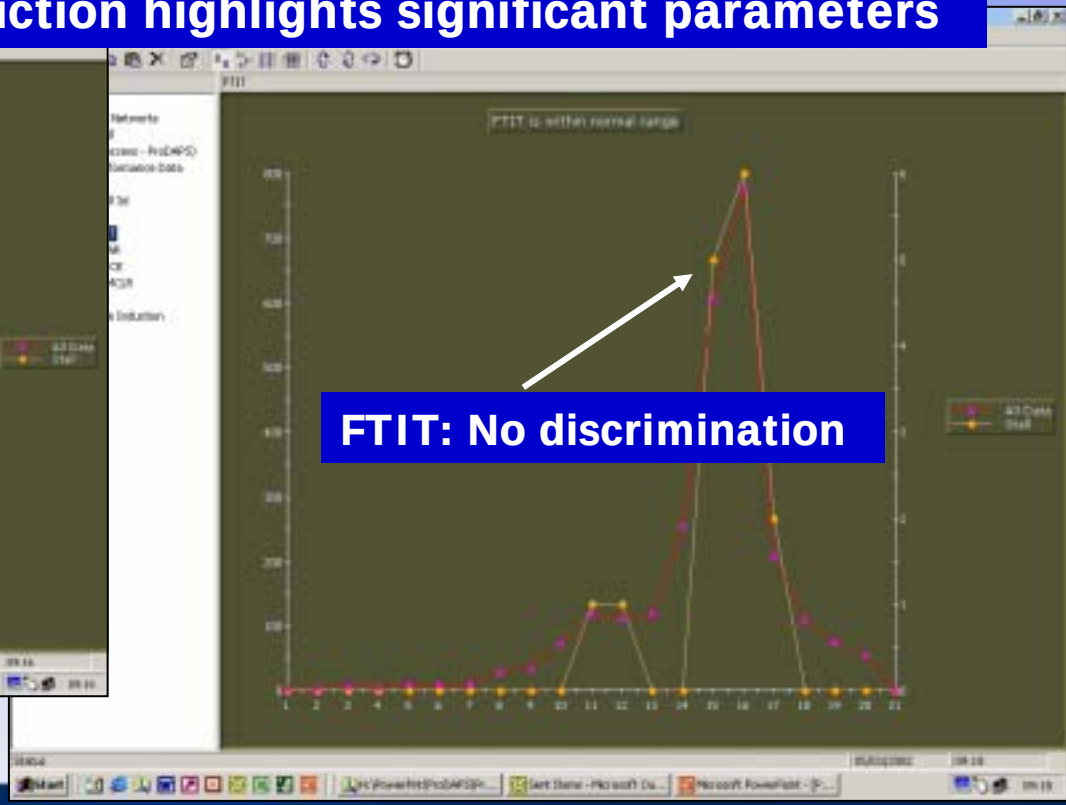
smiths

Data Mining Example: Investigation of Engine Stall Problem



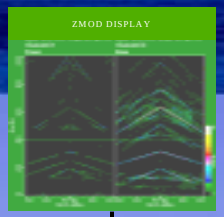
Further assessment: Rule induction highlights significant parameters





smiths

ProDAPS Architecture



Open Architecture

Vibration module

Oil module

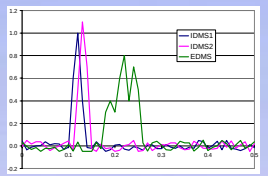
Performance module

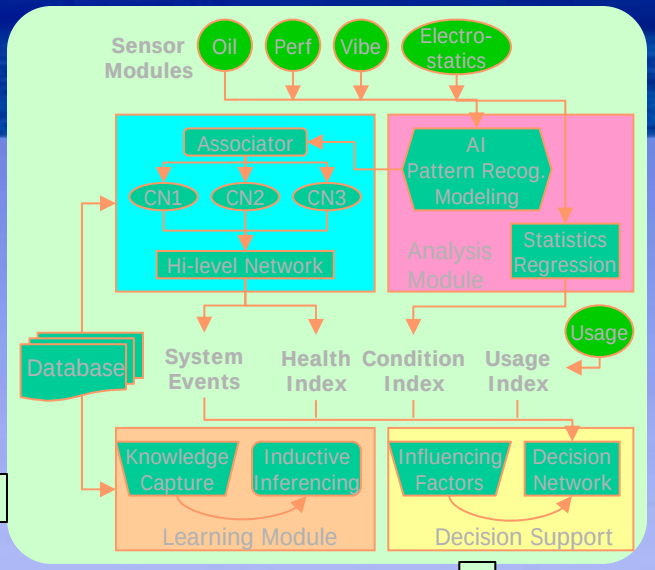
Usage module

HCF/LCF module

Engine Data

Electrostatics module





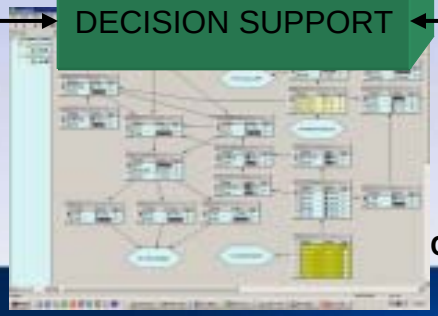
FUSION
Data Level
Feature Level
Decision Level

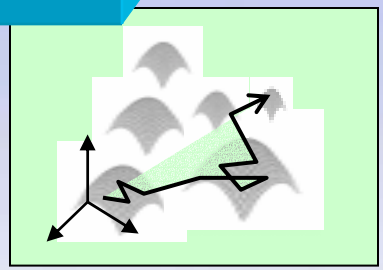
KNOWLEDGE DISCOVERY

DIAGNOSTICS

PROGNOSTICS

DECISION SUPPORT





Probabilistic Models

Components which can be configured for specific applications

smiths

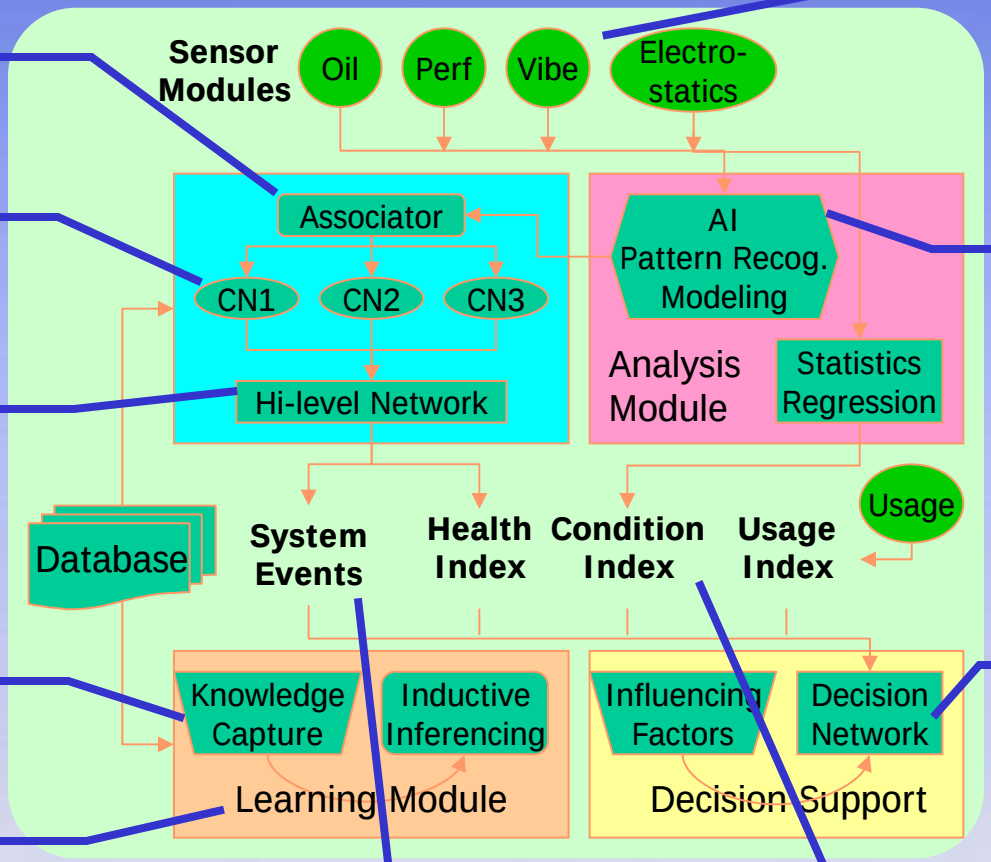
ProDAPS Key Elements

Probabilistic High Level Reasoning Engine

- Event routing facilitates temporal reasoning
- Multiple Causal Networks for knowledge-based reasoning
- Higher level reasoning based on multiple network outputs

Learning Module

- Directs search for new knowledge based on prior beliefs
- Induction learning tests and refines beliefs, discovers new knowledge



Sensor Modules

- Varying capabilities and levels of intelligence

Analysis Module

- Advanced tools for enhancing information from Sensor Modules

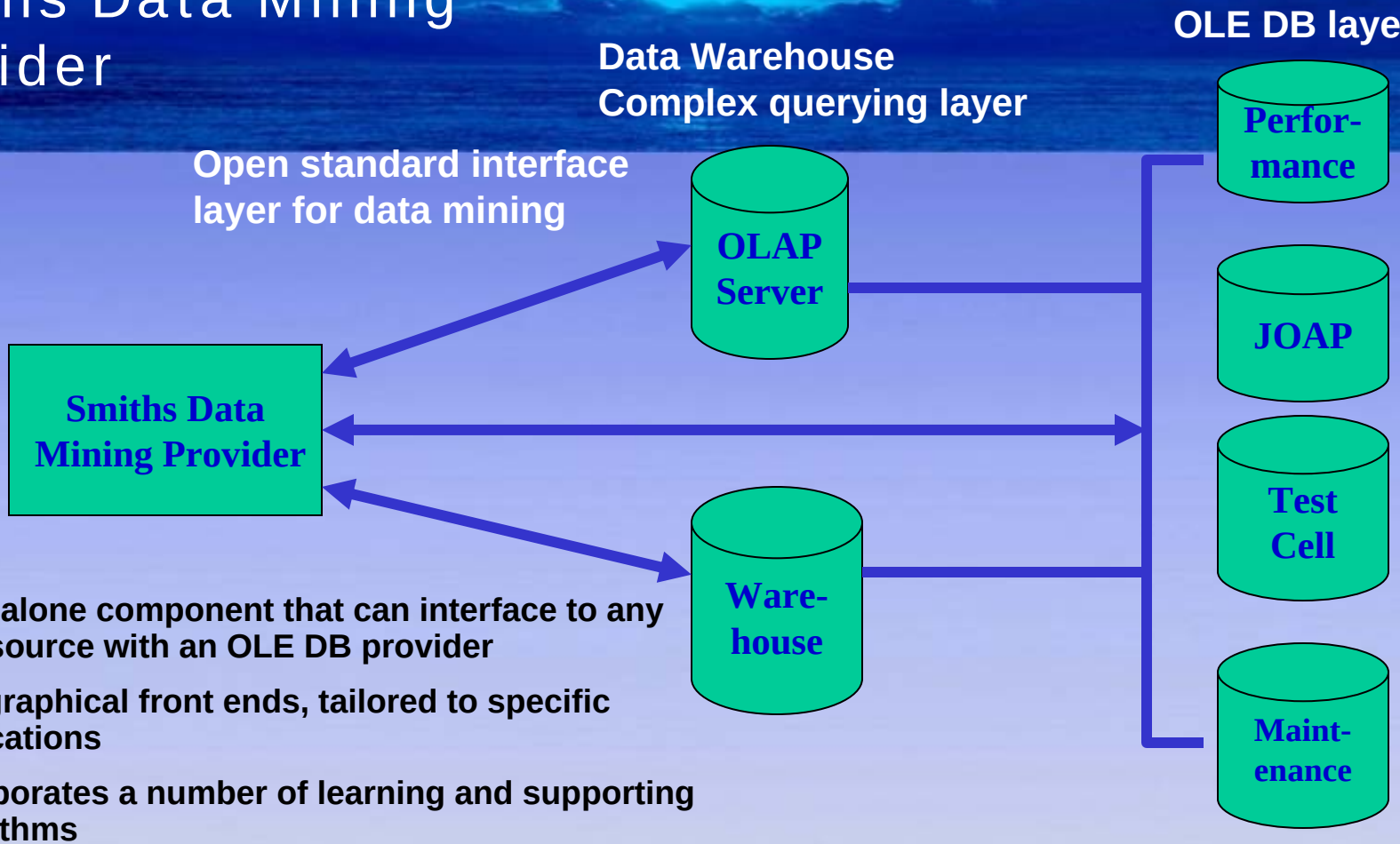
Decision Support Module

- Decision Networks provide support for optimum decision making by evaluating options

- Diagnostic Information
- Prognostic Information

smiths

Smiths Data Mining Provider

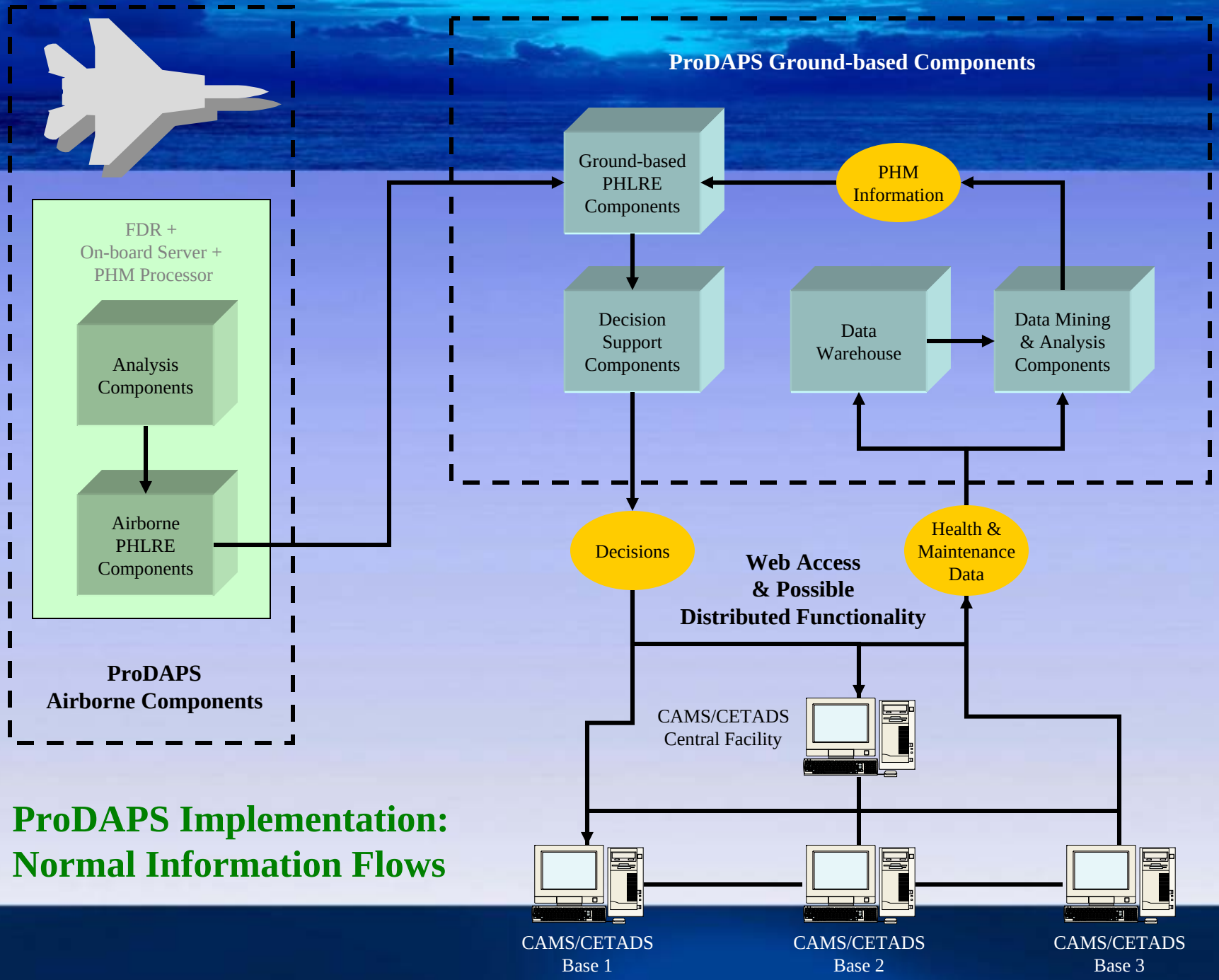


- Standalone component that can interface to any data source with an OLE DB provider
- Add graphical front ends, tailored to specific applications
- Incorporates a number of learning and supporting algorithms
- Manages results- tracks analysis in terms of inputs and outputs.
- Can generate XML reports of mining results
- Can operate over the WEB

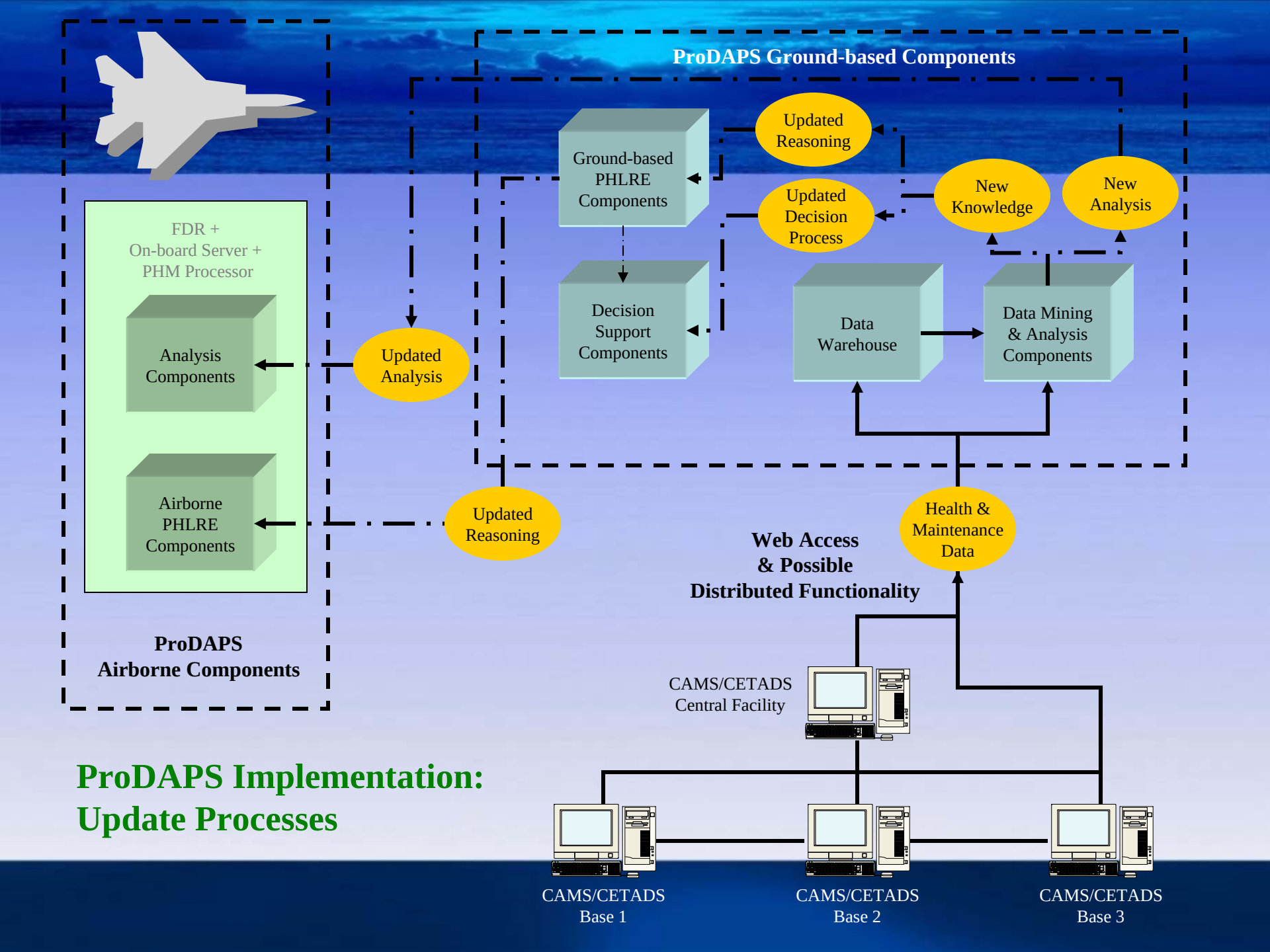
- Disparate Data Sources
- Legacy systems
- New Systems

- Different Databases
- Different locations
- Etc.

smiths



ProDAPS Implementation: Normal Information Flows



ProDAPS Implementation: Update Processes